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BEHAVIORAL SCIENCES

A HUMAN BODY VIBRATION DISPLAY

The human body is a mechanical system that responds to mechanical forces, so theoretically it should be possible to describe the system's responses and "resonances" to vibration and also to discover when vibratory stimuli can be expected to disturb output behavior. In practice, however, the great complexity of the whole system and of its many subsystems makes this descriptive task extraordinarily difficult. Nevertheless, G. Rasmussen (Brüel and Kgaer, Naerum, Denmark) has recently assembled much of the data about human response to vibration, and he has proposed a design for a portable "vibration-meter" instrument that would incorporate the data. The instrument receives vibratory signals, processes them by means of algorithms and stored "limit" data, and displays the likely human impact of a given exposure situation. This type of device may have significant value for studying man-machine interactions. There are still military and industrial environments, for example, in which men cannot remain long without suffering performance degradation or physical illness; at least some of the negative effects observed are attributable to vibration.

Figure 1 is Rasmussen's model of a human standing on a vertically moving base. The parameters listed reflect many experimental and practical measurements. Though summary representations like the one shown are necessarily crude and would not fit any one person perfectly, it appears that there are several important resonance peaks: thoracic resonance at 3 to 6 Hz, lower arm resonance at 16 to 30 Hz, and handgrip, intraocular structures, and skull resonating at higher frequencies.

For frequencies from 1 to about 80 Hz, discomfort and exposure-limit curves have been determined and published, and these are often recommended as environmental standards for certain time periods. As one example, a "standard human" would be expected to experience discomfort if exposed to a slow (5 to 6 Hz) and heavy ($3 m/s^2$) vertical vibration for 1 minute, and, according to the curve in Figure 2, such discomfort would be equivalent to a 16-minute exposure at an acceleration of only a little more than $2 m/s^2$. Exposure limits or allowed tolerances are roughly twice the discomfort accelerations, so it is common design practice to keep the effective vibration below the discomfort levels; this is especially true if critical motor or cognitive behaviors are demanded of the exposed human subject.

The tolerance-curve approach has been applied to estimating the human effects of pulses such as those from pile drivers, drop forges, heavy conveyors, and the rumble of trains over flexible platforms. According to Figure 3 on the following page, compiled by

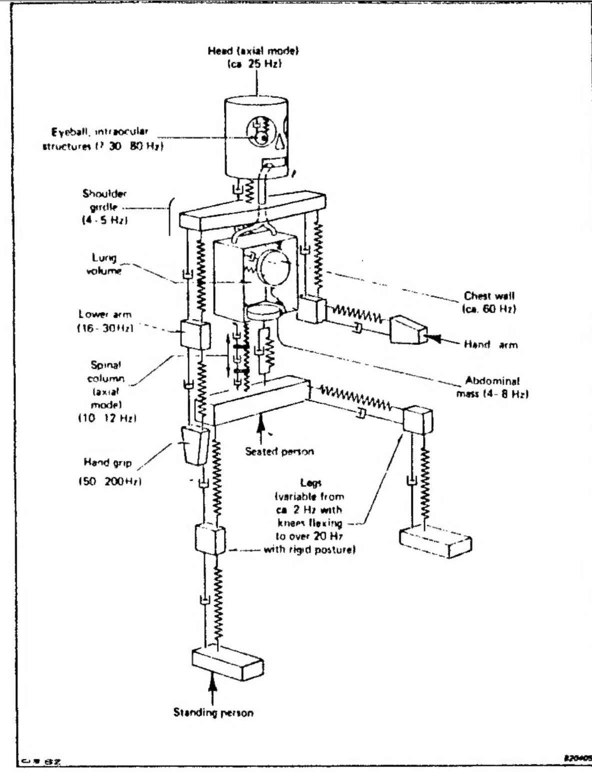

Fig. 1. Simplified mechanical system representing the human body standing on a vertically vibrating platform.

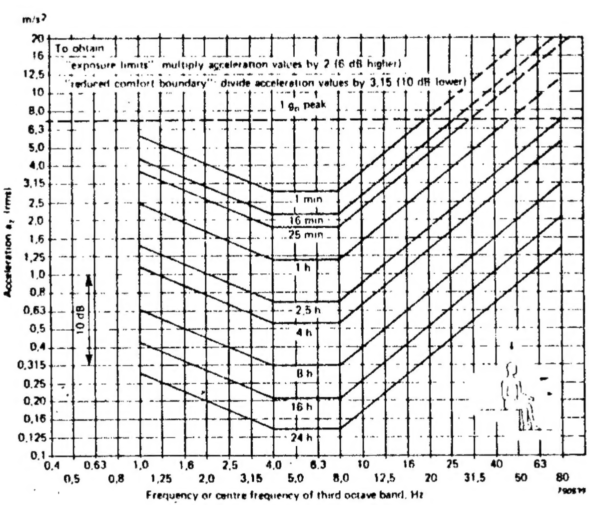

Fig. 2. Vertical vibration exposure criteria curves defining equal fatigue-decreased proficiency boundaries.

Rasmussen, there are three critical parameters: duration of pulse-rise time, maximum peak-to-peak displacement of the pulse, and the frequency of the pulse. Such limit curves are only guidelines, but they are believed to be appropriate for healthy persons who are already adjusted to reasonable job stresses. (The author visited a nearby London construction

site as this article was being written and observed that extremely unpleasant levels seemed to be reached there. Occasionally, two pile drivers were operating simultaneously, and if the main pulses were nearly superimposed, the subjective discomfort and aversion were pronounced. There was also a cognitive element; when both pile drivers were operating in a not-quite-regular rhythm, nearby observers could feel the frequencies converge on a simultaneous "hit"; the prediction of the hit, and the "hunching" in preparation for it, take considerable mental processing.)

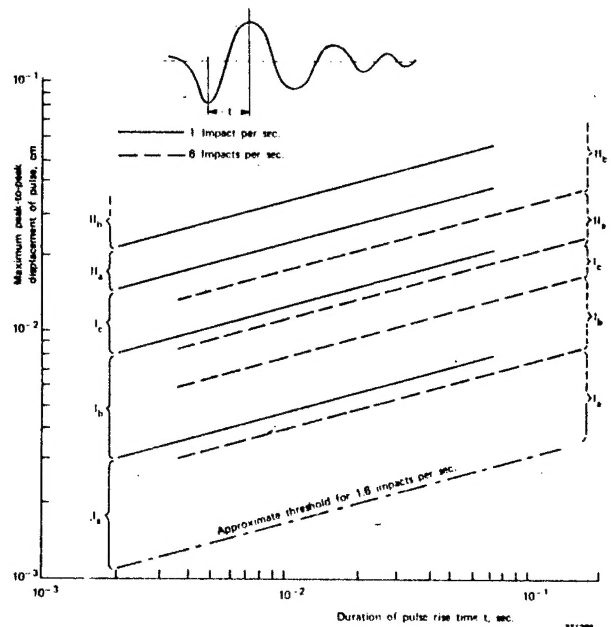

Fig. 3. Tolerance of human subjects in the standing or supine position to repetitive vertical impact pulses representative of impacts from pile drivers, heavy tools, heavy traffic etc. Subjective reaction is plotted as a function of the maximum displacement of the initial pulse and its rise time.

Tools such as chain saws, motorized grinders, and chipping hammers can cause physiological damage to the human operator when used for long periods. After only a few minutes of chain-saw work, partial numbness may be experienced in the hands; the effect is probably the cause of many chain-saw mishaps; as the grip is involuntarily loosened there is insufficient "grip feedback" from the hands. In extreme cases of long exposure to vibrating power tools, "dead hand" or Raynaud's disease, with permanent disability, may result. Rasmussen and others have plotted guideline-risk curves for hand-held tools; an example is shown in Figure 4. Permissible exposure limits can also be plotted as a function of time; human percentiles of "time exposed before very impaired performance" have been published, and it is likely that before long some of the guideline numbers will appear in damage clair and lawsuits. Manufacturers are concerned an are testing tools and handles that damp ou much of the vibration but still permit fir control and good feedback. "Remoting" of th man from the tool, along with partial robot ization, has already been accomplished in som industrial settings.

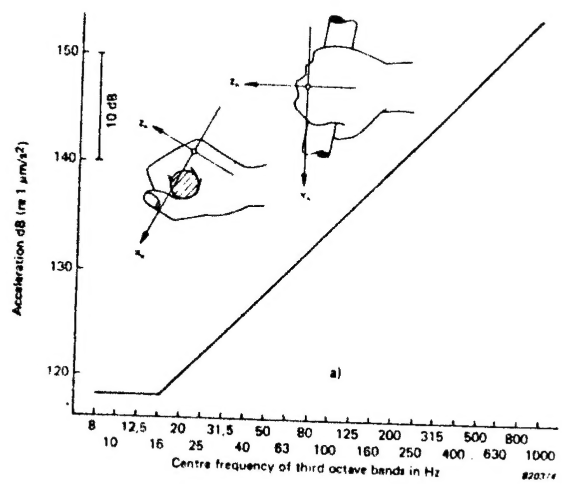

Fig. 4. Exposure guidelines for vibration transmitted to the hand.

There are many ways to measure vibration signals; all have advantages and drawbacks, and apparently no agreement has yet been reached among countries and laboratories on a norm. Among the possibilities are positive peak, negative peak, maximum peak, average rectified peak, and dose (acceleration integrated over time). Brüel and Kjaer recommends the use of rms acceleration (m/s^2) over a 1/3 octave frequency band, or over a 1-octave band for hand-held tools. Another measurement technique cites the level of vibration in db units; in this system, a vibration level is 20 times the $\log_{10}$ of the ratio of a weighted acceleration to a reference acceleration of $1 \mu m/s^2$. Rasmussen's weighting scheme uses different time constants for the several bands:

<1 s for the 0.1 to 1 Hz range
<10 ms for the 1 to 80 Hz range (whole body)
<1 ms for the 10 to 1,000 Hz range (hand/arm).

Decisions about which axes to sense will depend on the exposure situation. An overall rms-weighted acceleration can also be calculated; in research and evaluation studies, all the time constants should be quoted, as they can affect the computed outputs.

A practical device for assembling vibrational data into a functional display would then take as inputs such parameters as the accelerations and frequencies on the X, Y, and Z axes, the rise and decay time constants for each frequency band, and the signal-averaging constants. The calculated outputs would represent vibrational levels, perhaps in some

practical unit such as db. The outputs could also be presented in a qualitative display. Rasmussen's front-panel design (Figure 5) has separate display units for motion sickness, whole-body, and hand-arm readouts; simple switches are provided for such things as display mode and seat accelerometer specifications. There are many other features that could be added; the present design and the analyses underlying it will probably undergo extensive field trials in Denmark and other countries. The small package (front panel about 10x7 inches) could easily be put into any vehicle undergoing test and development. For detailed analysis of the vibrating situation itself, the instrument could be supplemented with additional multiaxial tape recorders, special transducers, and so forth.

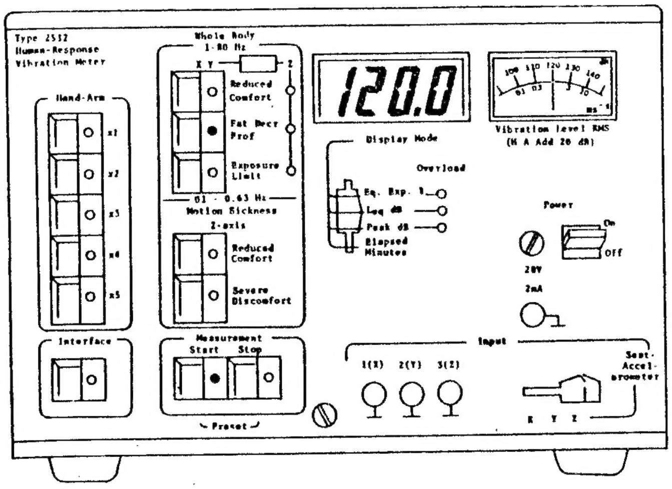

Fig. 5

The transmitted accelerations of hand-held vibrating implements are not the only parameters of interest; energy transmitted between hand and tool may be a biologically significant measure, and such energy depends on the mean and variance of grip pressure. To measure the energy coupling of hand and tool, Brüel and Kjaer has designed a special handle; it is made of light metal and has built-in accelerometers. Tests of the transfer function from tool handle to hand adaptor show a close tracking of vibrational levels between hand and handle, except for a slight overestimation of energy fed to the hand at around 1,000 Hz. Thus it would appear to be a conservative practice to take the handle-energy-level measurements as sufficient indicators of risky vibration. The adaptor handle, when fitted to a standard chipping hammer, measured some vibrations in the 150-db range; the trial showed good tracking between hand-adaptor levels and those recorded from a stud-mounted accelerometer on the tool itself.

Transducers and setup standards for seat and whole-body vibration are already available for most practical situations. With the development and refinement of compact devices like the Brüel and Kjaer meter, vibrational displays should become routine for many vehicles and work stations. The time may well be ripe for convening an international meeting on vibration to facilitate the sharing of techniques and ideas, to stimulate research and acceptance of standards, and to help ensure that there is no unnecessary overlap of projects.

N.A. Bond, Jr.

ONR London

VISIBILITY PROBLEMS IN JET AIRCRAFT

It is a bright European morning, with clear blue skies. Commercial jetliner A is proceeding on course at 33,000 feet. About 36 miles away is commercial jetliner B, which has a contrail some seven miles long behind it. Unknown to the pilots of either plane, the two airplanes have just been cleared to a collision course at the same altitude and are now closing at 800 miles an hour. After 2 minutes and 50 seconds on this course, the wing of jetliner A slices through the cockpit and cabin of jetliner B. All 176 persons aboard the two aircraft perish (amazingly, a couple of people, including a baby, survived the crash but died shortly thereafter).

The foregoing scenario, or something very much like it, occurred over Yugoslavia in 1976. As one of the worst mid-air crashes on record, it has been investigated by many boards and courts; damage suits and hearings are still going on. There is no dispute that poor air traffic controlling was one of the main causes of the accident. But the follow-on analyses showed that many other precipitating factors could be discerned. For example, there was a heavy workload on the air traffic controllers and bitter personal animosities among them. Another item was the usually innocuous request from the control center to aircraft A to put its altitude transponder on STANDBY; when it is set in that mode, there is temporarily no way for the controller to know the altitude of the aircraft.

At the cognitive level, there were also a number of possibly contributing factors. The pilot of aircraft B had been proceeding across Europe at 33,000 feet for some time, so he could reasonably expect that a protective block of air around him at that altitude would be maintained. On the other hand, all aircraft in the area must have known that the local area was extremely congested; aircraft A, for example, was not able to contact the upper sector controller for 2 minutes, because that controller was continually talking to other aircraft. Language may have been another contributing factor: despite the multi-lingualism required of all controllers, there are often problems with intelligibility; this is especially so in eastern Europe. In fact, a crucial part of the accident